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INVESTIGATION OF HIGH POWER GASEOUS
ELECTRONICS

Report No. 3

Contract No. DA-36-039-AMC-00097(E)

Technical Requirement No. SCL-5791

DA Task #1G6-22001-A-055-04

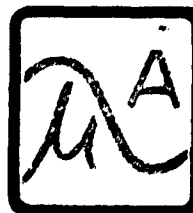
Third Quarterly Progress Report

16 May 1963 to 15 August 1963

U. S. Army Electronics
Research and Development Laboratories
Fort Monmouth, New Jersey

MICROWAVE
ASSOCIATES,
INC.

Burlington, Massachusetts



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Investigation of High Power Gaseous Electronics
Report No. 3

Contract No. DA-36-039-AMC-00097(E)

Technical Requirement No. SCL-5794

Dated: 24 June 1960

DA Task #1G6-22001-A-055-04

Third Quarterly Progress Report

16 May 1963 to 15 August 1963

Prepared by:

H. S. Maddix

J. Gregory

C. S. Ward

Approved by:

M. A. Allen

Objective: To theoretically and experimentally study gas discharge phenomena with application to duplexer tube operation at high power levels.

MICROWAVE ASSOCIATES, INC.
Burlington, Massachusetts

TABLE OF CONTENTS

	<u>Page No.</u>
TITLE PAGE.....	1
TABLE OF CONTENTS.....	11
LIST OF ILLUSTRATIONS.....	111
PURPOSE.....	iv
ABSTRACT.....	v
PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES.....	vi
FACTUAL DATA.....	vii
I. DETERMINATION OF ION FLUX.....	1
II. EXPERIMENTAL RESULTS.....	6
III. DISCUSSION.....	9
IV. CONCLUSIONS.....	12
V. PROGRAM FOR NEXT QUARTER.....	13
VI. IDENTIFICATION OF PERSONNEL.....	14
REFERENCES.....	15

LIST OF ILLUSTRATIONS

- Figure 1 Sorption of Krypton at 20°C
Figure 2 Desorption of Krypton at 900°C
Figure 3 Modified Clean-Up System
Figure 4 Sorption of Various Gases at 20°C Ambient
Figure 5 Arc Loss vs. Pressure

PURPOSE

The purpose of this program is to theoretically and experimentally investigate the nature of high power pulsed microwave plasmas in an effort to better understand and improve microwave gas switching techniques. The principal task to which we are devoting our efforts is a research program directed towards understanding the nature of gas clean-up.

ABSTRACT

Clean-up and thermal recovery of inert gases at the interface between a high power microwave discharge and a quartz interface have been further investigated. The ion flux to the discharge wall was found to be about 5×10^{19} ions/sec/cm² and to remain constant during a given clean-up run. The ion flux only varied by a factor of 2 for the five inert gases studied. From the experimental results it is evident that residual impurity gases desorbed from the walls of the clean-up vacuum system significantly affect initial clean-up and recovery behavior.

PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

Publications

The following paper was submitted for publication in the Transactions of the Tenth National Vacuum Symposium of the American Vacuum Society.

H. S. Maddix and M. A. Allen, "Activated Sorption of Inert Gases in an Electrodeless Discharge".

Conferences

June 4, 1963 and July 25, 1963 at Microwave Associates, Inc.

Mr. J. L. Carter, USAELRDL

A discussion of program plans with technical personnel on the contract took place.

No lectures or reports were issued during the period.

FACTUAL DATA

The following sections I through IV contain the factual data part of this report.

I. DETERMINATION OF ION FLUX

In order to further our understanding of the clean-up process, we must be able to define the ion flux to the quartz wall. In the previous quarterly report¹ we showed that Langmuir sheath theory is valid within the pressure range used in our experiments. The ion flux to the wall was shown to be

$$\Gamma_+ = n \sqrt{\frac{qT_-}{\epsilon M}} \quad (1)$$

where Γ_+ is the ion flux to the walls

n is the electron density

q is the ion charge

T_- is the electron temperature

ϵ is the base of natural logarithms

M is the ion mass

In the present report we shall complete the ion flux analysis by using arc loss theory together with experimental arc loss measurements to calculate electron density for five inert gases. With a knowledge of electron density we can calculate ion flux using Equation (1).

The discharge arc loss for a tube terminating a waveguide line is²

$$A = \frac{4}{\sigma Z} \frac{lh}{ab} \left(1 + \frac{a}{\pi l} \sin \frac{\pi l}{a} \right) \quad (2)$$

where A is the percent arc loss

l is the iris length

h is the iris height

a is the waveguide width

b is the waveguide height

σ is the discharge conductivity

Z is the characteristic waveguide impedance

For our experimental conditions Equation (2) reduces to

$$A = \frac{32.4}{\sigma^{1/3}} \quad (3)$$

In the pressure range of interest the discharge conductivity is²

$$\sigma = \frac{ne^2}{m\omega} \frac{1}{\left(1 + \frac{\nu_c^2}{\omega^2}\right)^{1/2}} \quad (4)$$

where e is the electron charge

m is the electron mass

ω is the radian microwave frequency

ν_c is the electron-atom collision frequency

The electron-atom collision frequency is defined by the relation³

$$\nu_c = \nu P_o P_c \quad (5)$$

where v is the electron velocity

p_0 is the gas pressure

P_c is the probability of collision

Equations (3), (4), and (5) can be combined to give the electron density.

$$n = \frac{2.23 \times 10^{15}}{A^2} (1 + \alpha p_0^2)^{1/2} \quad (6)$$

where the constant α is defined by

$$\alpha = \left(\frac{v P_c}{\omega} \right)^2 . \quad (7)$$

It is necessary to determine v and P_c for each gas. The probability of collision has been empirically determined as a function of electron energy for many different gases by several investigators³. The electron velocity can be found by using the Allis⁴ criterion which assumes that the mean electron energy is 0.3 times the lowest excitation potential of a given gas. A typical value of α is 1.85×10^{-3} .

On the above basis it is found that for the conditions encountered in our experiments that

$$1 < (1 + \alpha p_0^2)^{1/2} < 1.05 . \quad (8)$$

Accordingly, (6) can be reduced to

$$n \approx \frac{2.23 \times 10^{15}}{A^{\frac{1}{2}}}$$

We now have an expression in which electron density is a function of arc loss only. The results of an experimental determination of arc loss as a function of pressure for our particular discharge conditions is given by Figure 5. There is a degree of uncertainty in the absolute value of these measurements because of mount loss corrections; however, a reasonably high degree of accuracy can be assigned to the relative values.

Arc loss is independent of pressure at pressures greater than about 4 Torr for helium and neon, and at pressures greater than about 1 Torr for argon. In the case of krypton and xenon, arc loss is a minimum at about 1 Torr and is independent of pressure over a range of about 0.5 to 1.5 Torr. The operating pressure during clean-up runs was always in a flat portion of the curves and the pressure change during a particular run seldom exceeded 0.7 Torr. Arc loss and consequently electron density can thus be considered constant during a clean-up run.

We are now in a position to calculate ion flux by using Equations (1) and (9) to give

$$\Gamma_+ = \frac{2.23 \times 10^{15}}{A} \sqrt{\frac{qT_-}{eM}} \quad (10)$$

By using the Allis⁴ criterion for determining electron temperature, we end up with the following calculated ion fluxes:

TABLE I

Gas	Γ_+ ions/sec/cm ²
Helium	7.2×10^{19}
Neon	7.7×10^{19}
Argon	5.5×10^{19}
Krypton	6.4×10^{19}
Xenon	3.2×10^{19}

Thus we see that the ion flux to the walls is substantially constant during a given clean-up run and that the ion flux only varies by about a factor of 2 as the atomic weight of the five inert gases tested changes from that of Helium to that of Xenon.

II. EXPERIMENTAL RESULTS

Previous work¹ has indicated that typical clean-up and thermal recovery curves exhibit an initial rapid change of pressure with time, followed by a slower long term change of pressure. The initial clean-up and recovery varied erratically between runs but the long term clean-up and recovery was found to be consistently proportional to the square root of time. An examination of the data and experimental conditions suggests that the erratic initial portions of the clean-up and recovery curves is due to the presence of variable amounts of impurity gases evolved from the walls. In addition variations of long term square root clean-up rates also appear to be a function of impurity gas levels.

During the present quarter a series of tests were run to examine in greater detail the effect of the impurity gases. A quartz vial was degassed in the usual manner by baking for twenty-four hours at 900°C. A 1 mm fill of krypton was admitted to the vial and a clean-up test at an ambient temperature of 20°C was run. This was followed by thermal recovery at 900°C. Rather than change the gas fill by completely re-processing the vial, the original gas fill was left intact and the entire clean-up system was raised to a temperature of several hundred degrees centigrade for three hours. In this manner residual gases which absorbed on the walls of the clean-up system would slowly be evolved into the closed gas volume. At the conclusion of the three hour period the temperature in the clean-up system was reduced to 20°C. A subsequent clean-up run was performed and was followed by a 900°C desorption run.

This procedure was repeated with the clean-up system held for increasingly longer times at high temperature. The results of this test are shown in Figures 1 and 2. Each curve is marked with the number of hours that the clean-up system was held at high temperature to evolve impurity gases.

It is seen that the amount of gas sorbed and desorbed during the initial portions of the clean-up and recovery curves steadily increases with increasing time at which the system is held at high temperature. The long term clean-up and recovery is proportional to the square root of time as in previous work.

A closer examination of the long term square root clean-up rates in Figure 1, shows that the slopes differ by a factor of three. The largest square root clean-up rate is obtained from the eighty-five hour curve which represented the run with the greatest amount of impurity gas. In the case of the thermal recovery curves of Figure 2, it is seen that the long term square root slopes increase as the time in which the clean-up system is held at high temperature increases.

At the conclusion of this series of tests the system was evacuated and a fresh fill admitted. A new clean-up run at 20°C was made and results identical to the first runs on Figures 1 and 2 were obtained. This ability to repeat results with a fresh gas fill rules out the possibility of changes in either the quartz structure or in the pressure monitoring system.

The tests described above were performed with an ultimate pressure in the system prior to gas filling of about 5×10^{-7} Torr. In order to

determine if a higher degree of vacuum would affect results, the clean-up system was modified as in Figure 3. An additional ion gauge, cold trap and isolation valve were added between the clean-up system and the main vacuum system. When both valves V_1 and V_2 were opened the ultimate pressure in the system would be 5×10^{-7} Torr. However, when valve V_1 was closed and liquid nitrogen added to the outside of the cold trap, the pressure in the system was reduced to 5×10^{-8} Torr due to the freezing out of the impurity gases by the liquid nitrogen.

In order to apply this improved vacuum technique with a gas fill in the system it was necessary to first admit gas with valve V_1 and V_2 opened. Valve V_1 was closed and liquid nitrogen was applied to the cold trap. The system was left in this condition for about thirty minutes to allow time for the impurity gases to be frozen out in the cold trap. Valve V_2 was then closed and a clean-up and recovery test was run as before. The results showed no significant variation from the zero hour clean-up and recovery runs shown in Figures 1 and 2.

III. DISCUSSION

As a result of our experiments it was established that the degree of high vacuum that came into the system prior to gas filling is relatively unimportant when compared to the evolution of gases during prolonged heating of the clean-up system. This result can also be verified by some simple calculations. For example, if the total number of residual molecules in the isolated system at a pressure of 10^{-7} Torr were to be driven into the 0.3 cm^2 discharge area, this would only represent the sorption of about 0.001 equivalent monolayers of residual gas. This is indeed a small number when compared with the hundreds of equivalent monolayers of gas trapped in the discharge region as evidenced by the results of Figure 1. One equivalent monolayer is represented by the sorption of about 3×10^{15} molecules per square centimeter of discharge area.

The results of the prolonged bakeout can be clarified by making a conservative assumption that the equivalent of one monolayer of impurity gas such as water vapor is absorbed on the wall surface or just below the surface in the bulk of the quartz wall. This may be true even though the system is evacuated to a pressure of 10^{-7} Torr or better. A 900°C bakeout would desorb all gases, but as soon as the surface temperature is lowered significantly a monolayer of residual gas will be re-adsorbed within a few minutes. Desorption of this gas from the 0.3 cm^2 discharge area by the action of the discharge will result in the release of 10^{15} molecules per cm^2 . This is only a small fraction of the

observed clean-up. However, desorption from the entire 30 cm^2 area of the clean-up system could result in the desorption of 3×10^{16} molecules per cm^2 which is a more significant portion of the observed clean-up.

Apparently, the impurity gas has a relatively high diffusion coefficient in quartz as evidenced by the large changes during the initial stages of clean-up and recovery. It can be seen in Figures 1 and 2 that the major portion of this gas diffuses in and out of the quartz in a square root time value of less than 10. The fact that the long term square root clean-up and recovery rates increase with increasing impurity level indicates that a portion of the impurity gas has a lower diffusion coefficient comparable to that of krypton. Most likely the impurity gas represents a mixture of gases with different diffusion coefficients. Identification of species and partial pressures of the impurity gases can only be done with a mass spectrometer device.

One other significant factor has to be considered in analyzing the results. The pressure changes were monitored by a thermistor in which the sensitivity varies considerably from gas to gas. The greatest sensitivity is obtained from low molecular weight gases. For example, it was found that the sensitivity to helium was ten times greater than the sensitivity to krypton. If the thermistor is more sensitive to the impurity as is most likely the case, then the observed clean-up will be greater than is actually the case. On this basis adjustment of the apparent sorption of 22×10^{16} molecules per square centimeter during the initial sorption of the eighty-five hour curve in Figure 1 by a thermistor correction factor of 0.1 will result in a sorption of 2.2×10^{16}

molecules per cm^2 . This represents absorption of about seven equivalent monolayers of impurity gases which is probably a more realistic value.

On the basis of the above analysis the clean-up runs obtained doing earlier work¹ have been re-evaluated. Figure 7 from the previous quarterly report¹ which shows the sorption of five inert gases at an ambient temperature of 20°C has been replotted in Figure 4. Correction factors have been applied to the initial clean-up period to account for the difference in thermistor sensitivity between the test gas and the impurity gas. This rework of the data gives a clearer presentation of the variation in long term clean-up rates with increasing atomic weight. In addition the question of the anomalous initial clean-up behavior of neon is clarified. When the effects of the impurity gases are properly weighed it is seen that the initial clean-up behavior of neon does not differ significantly from that of the other inert gases.

IV. CONCLUSIONS

The ion flux out of electrodeless discharge being studied is about 5×10^{19} ions/sec/cm² and only varies by a factor of 2 as the atomic weight of the test gases varies from that of helium to that of xenon. The ion flux is independent of pressure within the experimental pressure ranges and consequently the ion flux is constant during a given clean-up run.

Residual impurity gases desorbed from the walls of the clean-up system significantly affected initial clean-up and thermal recovery behavior. Long term clean-up and recovery rates were also affected by impurity gases although to a lesser extent. The impurity gases exhibited the greatest effect during clean-up runs for the heavier gases because under these conditions the relative response of the thermistor pressure gauge was greatest for the impurity gases and least for the high molecular weight test gases.

V. PROGRAM FOR NEXT QUARTER

1. Investigate means of reducing the level of impurity gases desorbed from the vacuum system walls during clean-up and thermal recovery runs.
2. Investigate clean-up and thermal recovery behavior for different conditions of peak power and average power.

VI. IDENTIFICATION OF PERSONNEL

This section contains a list of key technical personnel assigned to the contract and taking part in the work covered by this report. The approximate man hours of work performed on the contract by each of the people listed are given.

20 May 1963 to 18 August 1963

<u>Name</u>	<u>May (from 20th)</u>	<u>June</u>	<u>July</u>	<u>Aug. (thru 18th)</u>	<u>Total</u>
H. S. Maddix	24	102	76	24	226
J. Gregory	40	64	152	40	296
C. S. Ward	10	22	-	-	32
M. A. Allen	12	24	20	11	67
				Total	621

REFERENCES

1. H. S. Maddix, J. Gregory and C. S. Ward, "Investigation of High Power Gaseous Electronics", Report No. 2, Contract No. DA-36-039-AMC-00097(E), U. S. Army Signal Corps Engineering Laboratories (1963).
2. C. S. Ward, N. J. Brown, "High Power Microwave Switching Devices", Final Progress Report (Oct. 1961) Contract No. NObsr 77586 (1734F).
3. S. C. Brown, "Basic Data of Plasma Physics", John Wiley & Sons, Inc. New York (1959).
4. W. P. Allis, "Handbuch der Physik", 21, 418, Springer-Verlag (1956).

FIGURE 1

SORPTION OF KRYPTON AT 20°C

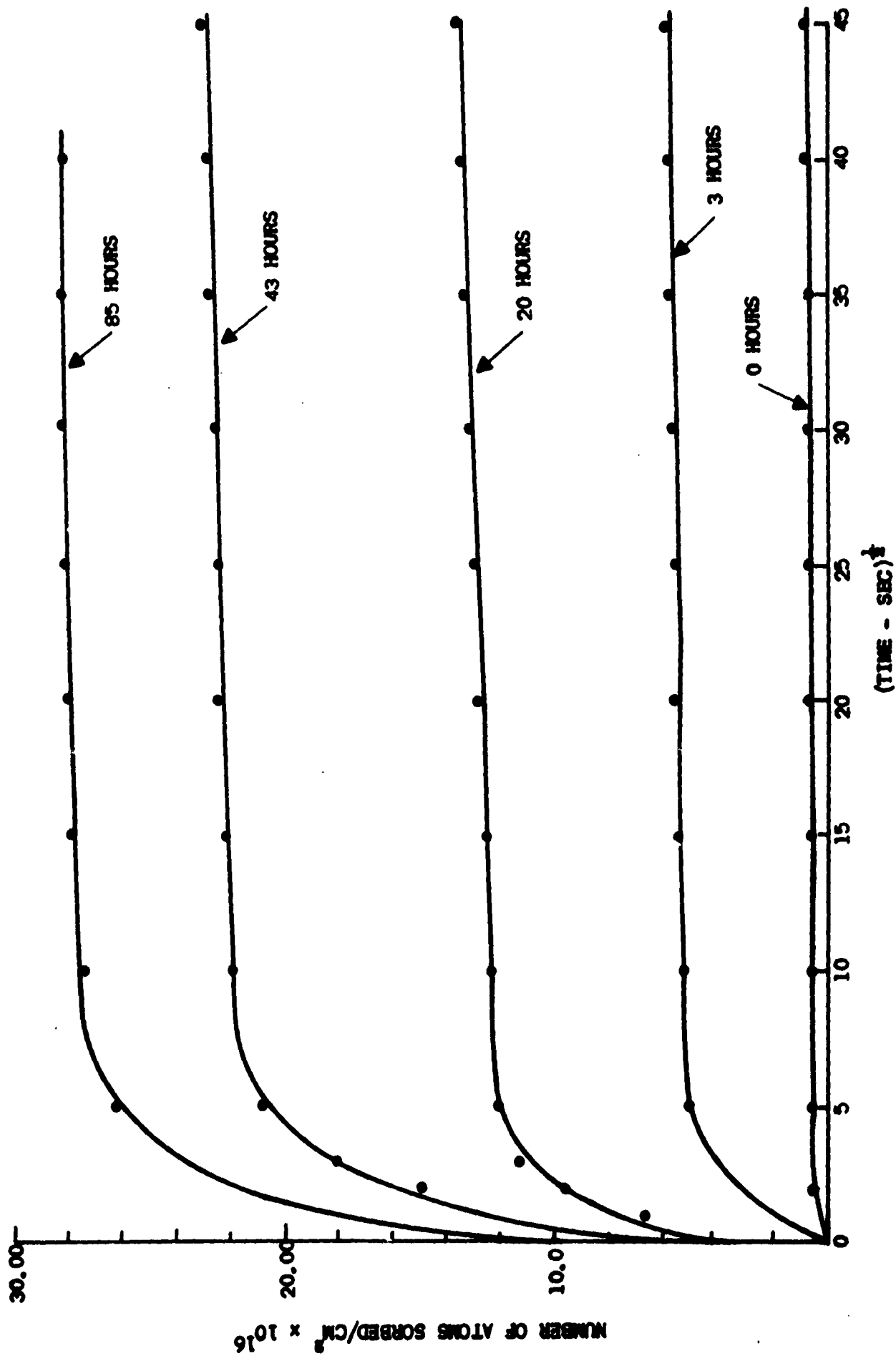
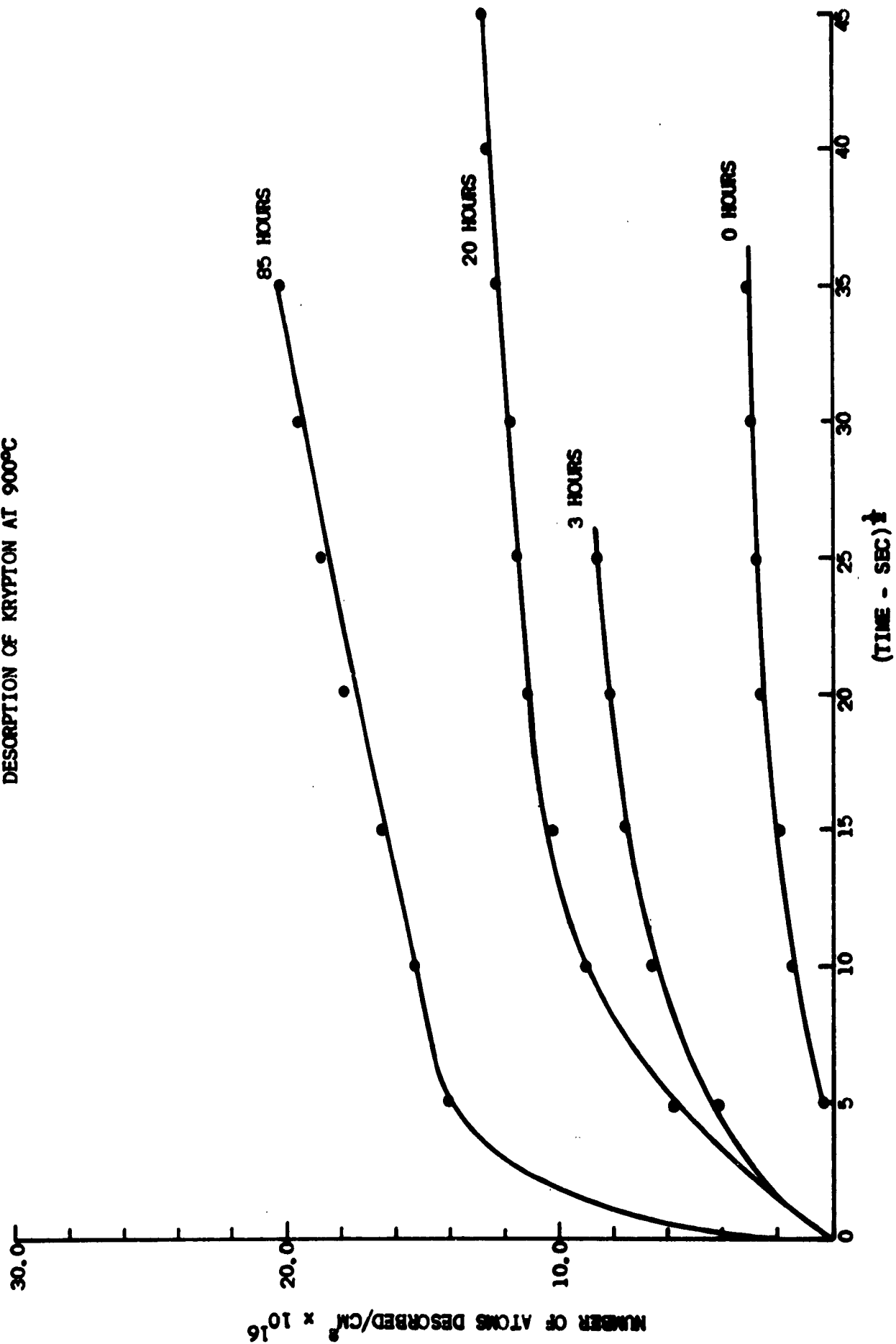


FIGURE 2
DESORPTION OF KRYPTON AT 900°C



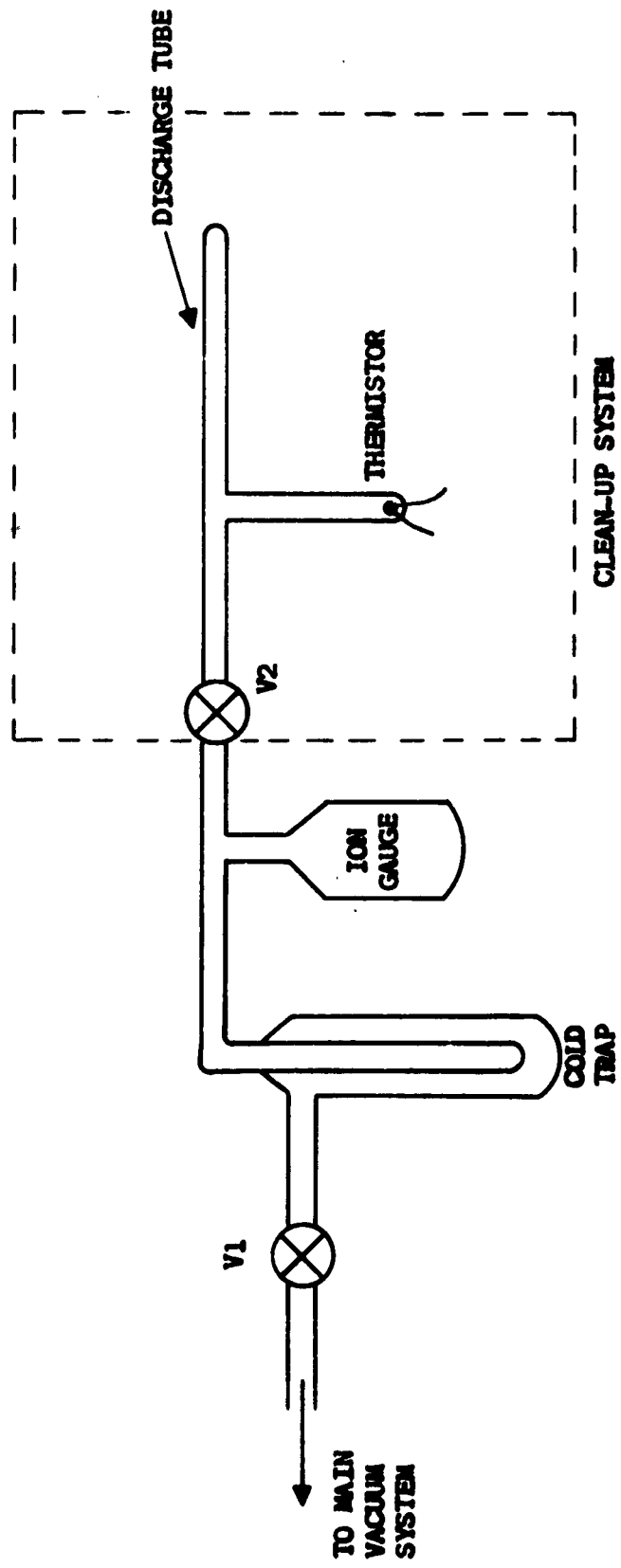


FIGURE 3
MODIFIED CLEAN-UP SYSTEM

FIGURE 4

SORPTION OF VARIOUS GASES AT 20° C AMBIENT

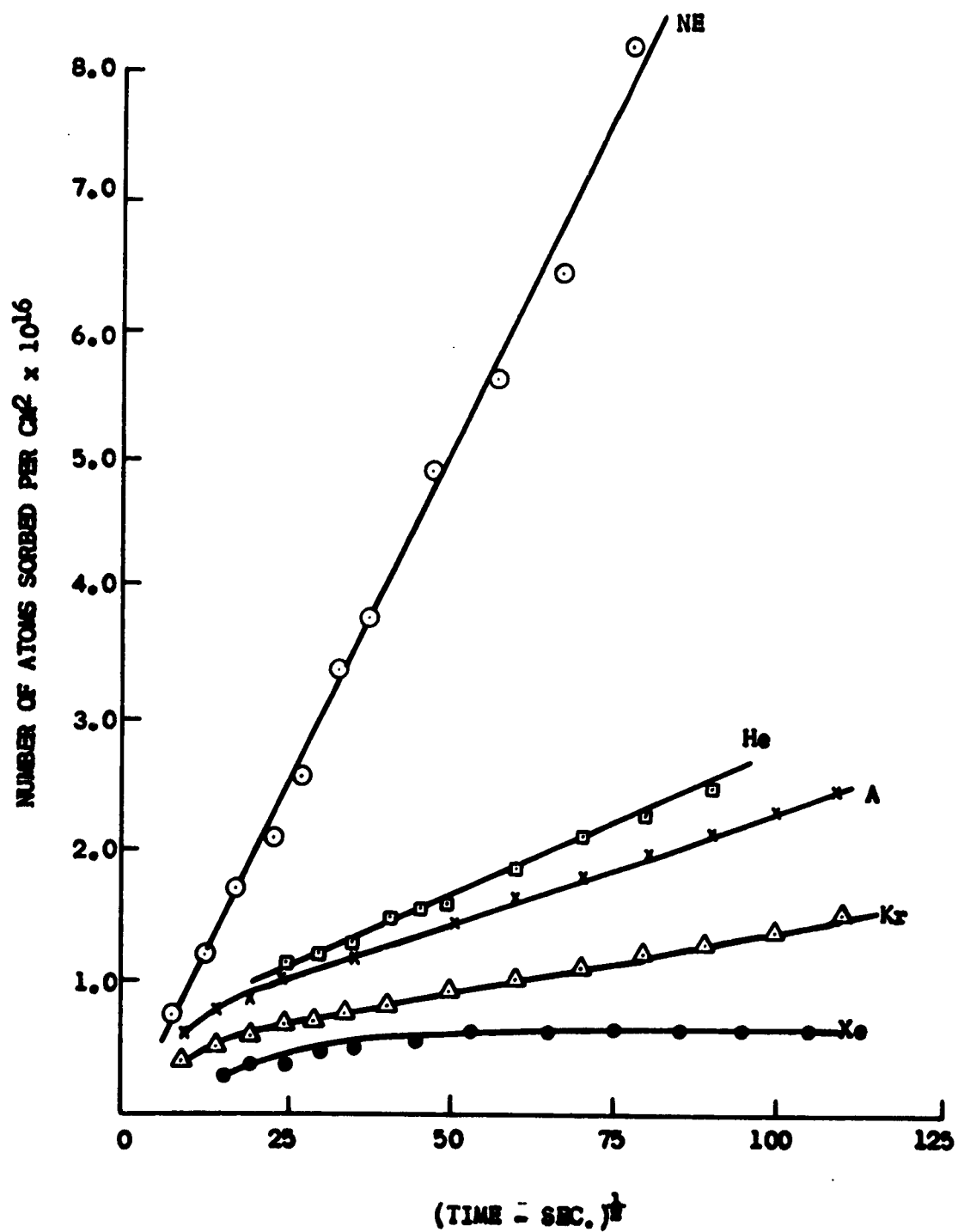
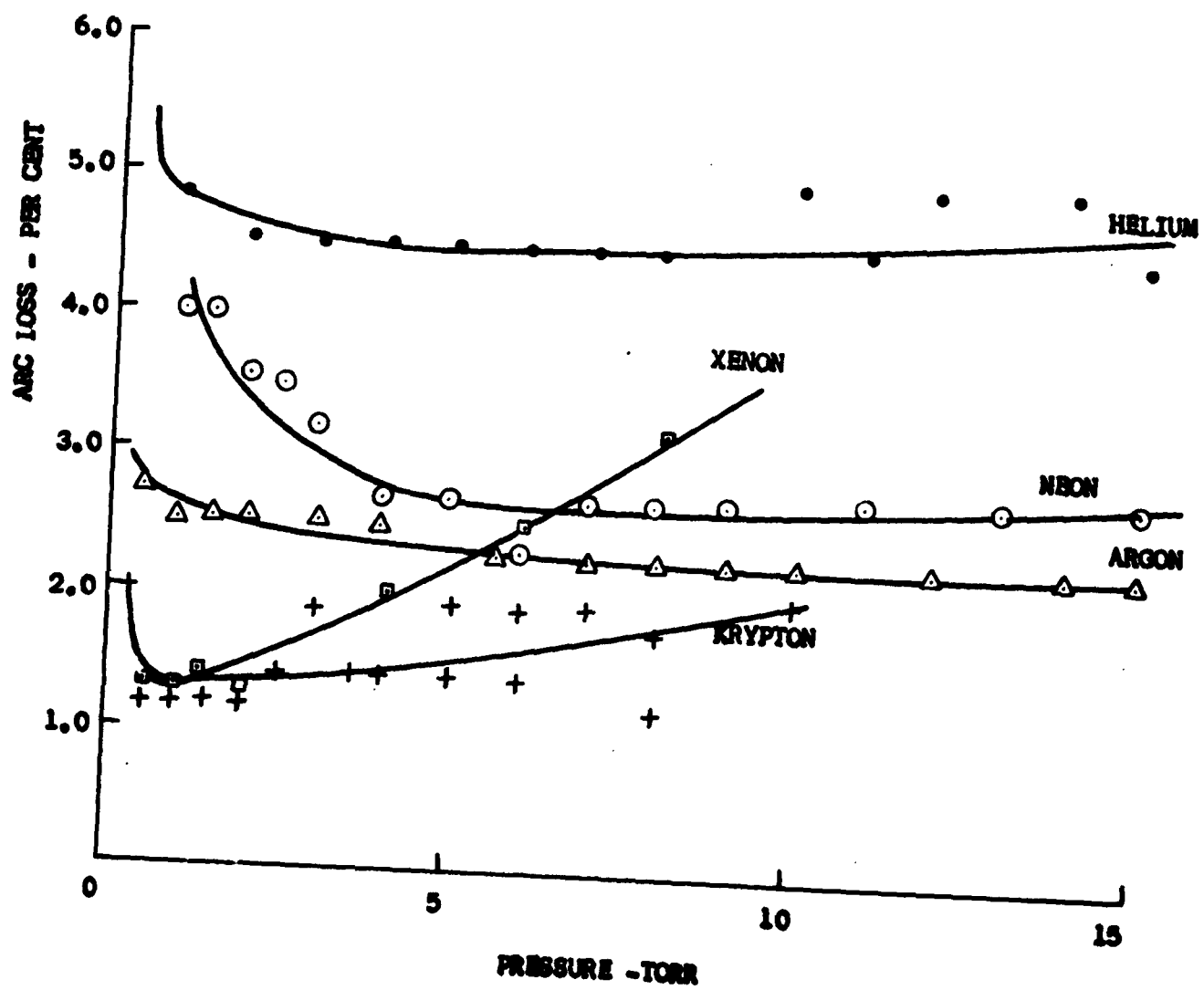


FIGURE 5
ARC LOSS VS. PRESSURE



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This contract is supervised by the Microwave Tubes Branch, Electron Tubes Division, FCD, USAELRDL, Fort Monmouth, New Jersey. For further technical information, contact Mr. John Carter, Project Engineer, Telephone 201-59-61742.